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AN INFRARED MARS PROBE FOR
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AN INFRARED MARS PROBE FOR
GATHERING EVIDENCE ON
EXTRATERRESTRIAL LIFE

Richard W. Davies
Max Gumpel

Presented at

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**AN INFRARED MARS PROBE EXPERIMENT FOR GATHERING
EVIDENCE OF EXTRATERRESTRIAL LIFE***

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ABSTRACT

The Earth's atmosphere is opaque to most of the infrared band between 1 and 100 microns. One of the partial windows between 3 and 4 microns gave Sinton an opportunity to detect three small dips in the reflection spectra associated with the visual dark regions of Mars. The dips are not associated with the light arid areas of the planet. One small dip (on the shoulder of the descending spectrum) is at 3.43 microns. All C-H bond molecules heavier than methane have a strong infrared resonance absorption at 3.46 microns. It is quite probable that organic matter is on Mars, but its origin is still an open question. More infrared reflection spectra of biological materials are needed, particularly in spectral regions where molecules of biological origin have very definite characteristics.

*This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract No. NASw-6, sponsored by the National Aeronautics and Space Administration.

**Assisted by the National Academy of Sciences, Space Science Board and Bioastronautics Committee.

Calvin has recently measured the reflection spectra of milled nylon which has a peptide linkage such as is found in proteins. Two strong reflection peaks due to C-O stretching are found in the 6-micron region. This spectral region is opaque to the Earth's atmosphere.

A stabilized space probe passing within 10^6 km of Mars could make a 12 x 12 line scan of a planet in the 3- to 7-micron region with a 500-Å bandpass. The spectra would be correlated with the visual light and dark areas of Mars. The experiment would be significant with no more than a few thousand bits of information transmitted to the Earth.

An accompanying experiment would be to measure the light polarization of Mars as function of the probe-Mars-Sun angle. Terrestrial measurements, which require 6 years, are limited to an angle of 43 deg maximum. A single pass by a probe could make polarization measurements up to a 90-deg phase angle. These polarization measurements would give some additional information on the sizes of particles in the Martian atmosphere.

I. INTRODUCTION

The scientific concept of the experiment described in this paper is very modest. However, we believe that the space technologies of the Soviet Union and the United States are sufficiently well developed to attempt this experiment within the next few years. We estimate these technologies to be of sufficient capability to:

1. Place a probe within 10^5 km of Mars
2. Track the probe on a world radio-telescope net and receive telemetered data on a 1- or 2-cycle bandwidth out to 2×10^8 km.

Both capabilities imply that the spacecraft be attitude controlled upon command to within 0.1 deg and that the equipment on board the spacecraft be operable several months after launch.

Recent data obtained by Sinton (Ref. 1) from infrared spectroscopic observations of Mars tentatively indicate the presence of organic molecules in the region Syrtis Major of the planet. The Earth's atmosphere is opaque to most of the infrared spectral band. There is a partial window between 3 and 4 microns which enabled Sinton to detect three small absorption dips at 3.43, 3.56, and 3.67 microns. These dips are associated with the dark areas of Mars and not the orange desert regions. The equatorial region Syrtis Major had the most prominent absorption spectra. The most interesting absorption feature is the 3.43 dip because all organic molecules have a strong absorption band at 3.46 microns as a result of a resonance of carbon-hydrogen bonds. It must be noted, however, that the 3.43 dip observed by Sinton is very weak and occurs on the

shoulder of a descending spectrum. (Methane and water vapor have absorption bands at 3.3 and 3.1 microns, respectively.) It is necessary to subtract the Sun's spectra from the Mars spectra in order that the 3.43 dip be evident. Observations by Shaw, Burch, and Cummins (Ref. 2) partially verify Sinton's observations.

It is well known that the dark areas of Mars wax and wane with the seasons, and it has often been suggested that these areas are vegetation. The Soviet astronomer I. K. Koval (Ref. 3) has observed that the light reflected from the maria, in contrast to light from the orange areas, does not follow Lambert's cosine law. That the surface of the maria is rough is one obvious interpretation of these observations.

The next Mars opposition which occurs late in 1960, is a propitious time to repeat Sinton's experiment in many observatories, and, if possible, to employ more sensitive infrared detectors such as zinc-doped germanium at liquid helium temperatures.

II. SCIENTIFIC EXPERIMENTS FOR MARS PROBE

In answer to the question of how to gather more evidence on whether or not the surface molecules of the Martian maria are of biological origin, the Westex Committee¹ suggested that a spectral region be chosen in which biological molecules had more characteristic features than C-H bonds. Such a region is that between 5 and 7 microns.

In the 5- to 7-micron region, Mars emits from 20 to 100 times as much radiation as it reflects (see Fig. 1). (The opposite is true in the 3- to 4-micron region.) If R_λ is the radiating curve of a black radiator and r_λ is the reflectivity of the Martian maria, the emitted radiation of Mars is $(1 - r_\lambda)R_\lambda$.

M. Calvin and A. Baker ran an infrared reflection spectra between 5 and 7 microns on milled nylon (Fig. 2). Nylon has a peptide linkage such as is found in proteins. It should be noted that there are two large reflection peaks at wave numbers 1641 (5.75 μ) and 1532 (6.5 μ). If the Martian maria carry a high surface concentration of peptide linkage, the radiation curve would be expected to exhibit two dips at wave numbers 1641 and 1532. The presence of water or other complex organic molecules smear these spectral characteristics. (See Tables 1, 2, and 3.) It is very improbable that the surface of Mars will radiate characteristics so definite as to conclude it is covered with proteins. However, any results would be helpful. If, in the 5- to 7-micron region, the maria radiated

¹The Westex Committee is an ad hoc subcommittee of National Academy of Sciences Space Science Board concerned with exobiology.

like a black body (emissivity 1), the presence of many complex organic molecules would be suspected.

It is important to be able to compare spectra of the maria with those of orange arid regions. An atmospheric constituent could absorb enough of the radiation to wash out all spectral characteristics, and there would be no way of differentiating between atmospheric and surface causes. For example, water has a broad absorption band between 4 and 8 microns and is peaked at 6 microns. The water-vapor content of the Martian atmosphere is extremely small, yet enough to absorb from 10 to 50% of radiation at 6 microns, depending upon whose data one considers the most reliable.²

A. Infrared Experiment

A spacecraft is visualized with its central axis and solar panels oriented toward the Sun and a directional antenna pointed toward the Earth, as shown in Fig. 3. Mars overtakes the spacecraft a few months after launch, at which time their relative speeds are 8 to 9 km/sec. The optical system can rotate from the central axis as much as 100 deg. If closest approach to Mars is 10^5 km, the optical system can see Mars at 4×10^5 km by rotating 85 deg from the central axis. Mars would then pass by the probe within a distance of 4×10^5 km (± 85 -deg look angle) in a little over 24 hours, or one Martian day. At 10^5 km, the planet

²The balloon telescope of Ross, Moore, and Strong may obtain some valuable information about the water vapor content of the Martian atmosphere if their ascent is as successful for the next Earth-Mars opposition as it was when viewing Venus in 1959.

subtends an angle of 3.8 deg; therefore, a 12 x 12 mechanical scan of planetary surface is within the capabilities of an attitude-control system designed for deep-space communication.

The miss distance theoretically limits the type of infrared detector and the design of the spectrophotometer. The figures in the following tabulation show that radiation collection is not a problem out to 10^6 km.

$E_r \equiv$ reflected power, watts/micron

$\tilde{E}_r \equiv$ emitted grey body power, watts/micron

$A \equiv$ area of reflector, cm^2

Mars temperature, 250°K

Sun temperature, 6000°K in infrared (Petit and Nicholson)

$$E_r (3.4 \mu) = 6 \times 10^{-8} A \text{ watts } \mu^{-1}$$

$$\tilde{E}_r (3.4 \mu) = 0.6 \times 10^{-8} A \text{ watts } \mu^{-1}$$

$$\tilde{E}_r (5.7 \mu) = 1 \times 10^{-8} A \text{ watts } \mu^{-1}$$

$$E_r (6 \mu) = 0.9 \times 10^{-8} A \text{ watts } \mu^{-1}$$

$$\tilde{E}_r (6 \mu) = 18 \times 10^{-8} A \text{ watts } \mu^{-1}$$

$$E_r (6.5 \mu) = 0.7 \times 10^{-8} A \text{ watts } \mu^{-1}$$

The above values of radiation intensity would be observed by a probe 10^5 km distant from Mars. The experiment would be significant if the spectral resolution were no better than 750 \AA between 3 and 7 microns and the scan no finer than 6 x 6 lines. A 12 x 12 scan and a $500\text{-}\text{\AA}$ bandpass spectrophotometer system would require a 25-cm diameter reflector and a simple bolometer detector. A 50-cm reflector and a PbSe detector at 100°K could perform the same measurements at 10^6 km.

It is evident that, at miss distances of only 10^5 km, there is considerable latitude in choosing a system. By using the larger reflector and the more sensitive PbSe detector, a much higher resolution can be achieved. A smaller reflector is more maneuverable, however, and a less sensitive detector does not require as accurate temperature control. If observations made later in 1960 indicate that Mars has considerably more water vapor in its atmosphere than the latest estimates indicate, it would probably be best to employ a large reflector and a bolometer detector in order to look farther into the infrared.

It is the limited information bandwidth which restricts the scientific system. If the bandwidth is one cycle at 10 db signal-to-noise ratio, it would require almost 4 hours to transmit the spectrum between 2 and 10 microns (with $500\text{-}\text{\AA}$ bandpass) of a 12×12 planetary scan. It would require 20 min to transmit the spectrum between 3 and 7 microns (with $750\text{-}\text{\AA}$ bandpass) on a 6×6 planetary grid. The probe could transmit the information intermittently for a week or two following the time of its closest approach to Mars. Full utilization of the system, therefore, necessitates the use of information storage.

A detailed description of the optical system is presented in the Appendix.

B. Polarization Experiment

The polarization measurements by Lyot, Dollfus, and Cailleaux suggest another experiment which logically accompanies the infrared experiment, although, in some respects, it is superior.

Dollfus (Ref. 4) has measured the polarization of light reflected from different areas of Mars as function of the Earth-Mars-Sun angle. The maximum

angle is 43 deg. In 1948, Dollfus found that the polarization curve of the equatorial areas differed from that of the northern areas. In 1950, he found that the polarization curve of the Northern hemisphere dark areas for the autumn-winter season differed from that of late spring.

If the spacecraft takes a flight trajectory to within 10^5 km of Mars, the polarization of light from that planet can be measured for all probe-Mars-Sun angles up to 90 deg. For an angle of 89 deg, the probe would be 4×10^5 km distant, the point at which the infrared experiment would also commence operation.

C. Subsequent Mars Experiments

The experiment described in this paper is merely the first step in a logical program. The next step would be to reverse the solar panels and fly on the dark side of the planet. The same apparatus could then measure the transmission through the atmosphere and determine its constituents. This requires improved guidance.

An even more sophisticated experiment would be to place a satellite around Mars and to measure the temporal variations of the infrared spectra, and the light polarization.

III. CONCLUSIONS

This is an opportune time to initiate an international program in exobiology which includes the use of interplanetary vehicles, telescopes, and terrestrial-bound telescopes. The experiments described in this paper are tentatively suggested as part of a program which should be executed in the next few years, unless the observations made during the 1960 Earth-Mars opposition indicate another approach. The space technologies of the United States and the Soviet Union are sufficiently well developed to attempt these experiments, which are intended to verify and extend the work of Sinton, Strong, Dollfus, Kuiper, Tikhov, and others, on the central Martian question, namely, do organic molecules of biological origin lie on surface of that planet?

Table 1. Absorption Dips Found by Sinton

Wavelength μ	Wave number cm^{-1}
3.67	2725
3.56	2809
3.43	2915

Table 2. Absorption Peaks in 3.4- to 3.7-micron Region
for Some Organic Compounds

Compound	Wavelength μ	Wave number cm^{-1}
Formaldehyde (HCOH)	3.60	2778
Acetaldehyde ($\text{CH}_3\text{CHO-H}$)	3.69	2710
Methylamine ($\text{CH}_3\text{-NH}_2$)	3.55	2817
Methyl ether ($\text{CH}_3\text{-O-CH}_3$)	3.43	2915

Table 3. Absorption Bands in 5- to 7-micron Region

Compound	Wavelength μ	Wave number cm^{-1}
CO absorption primary amides	6.1	1650
NH ₂ deformation primary amide (II)	6.2-6.3	1650-1620
Amino acids	5.0	2000
Amino acids	7.7	1300

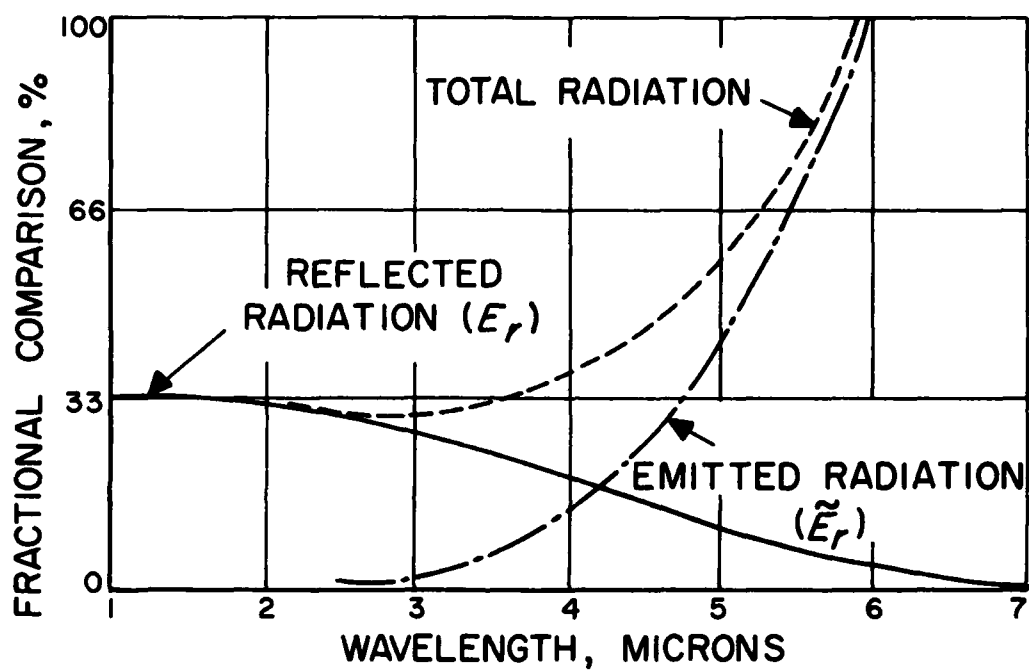


Fig. 1. Comparison of Emitted and Reflected Radiation

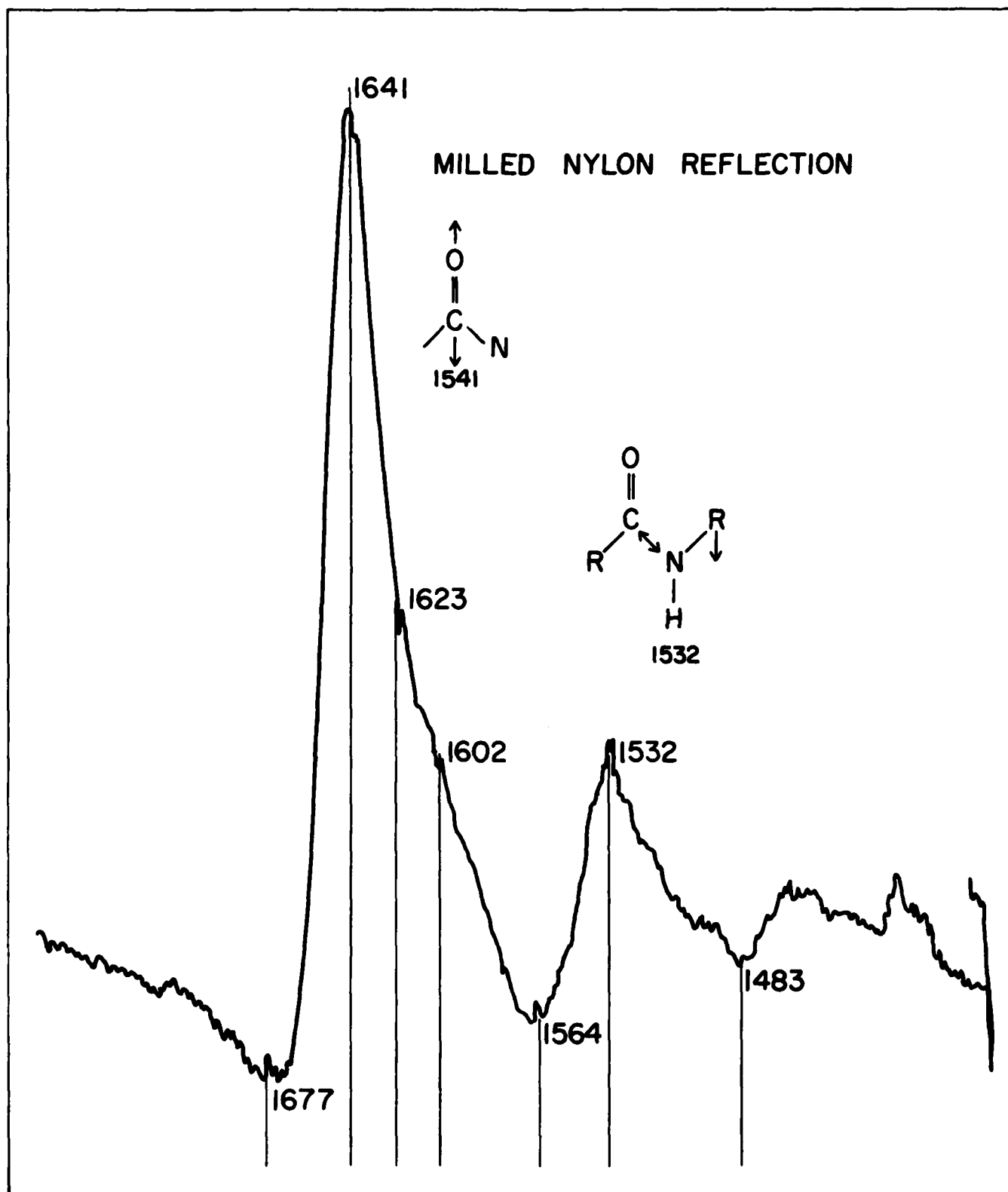


Fig. 2. Infrared Reflection Spectra of Peptide Linkage

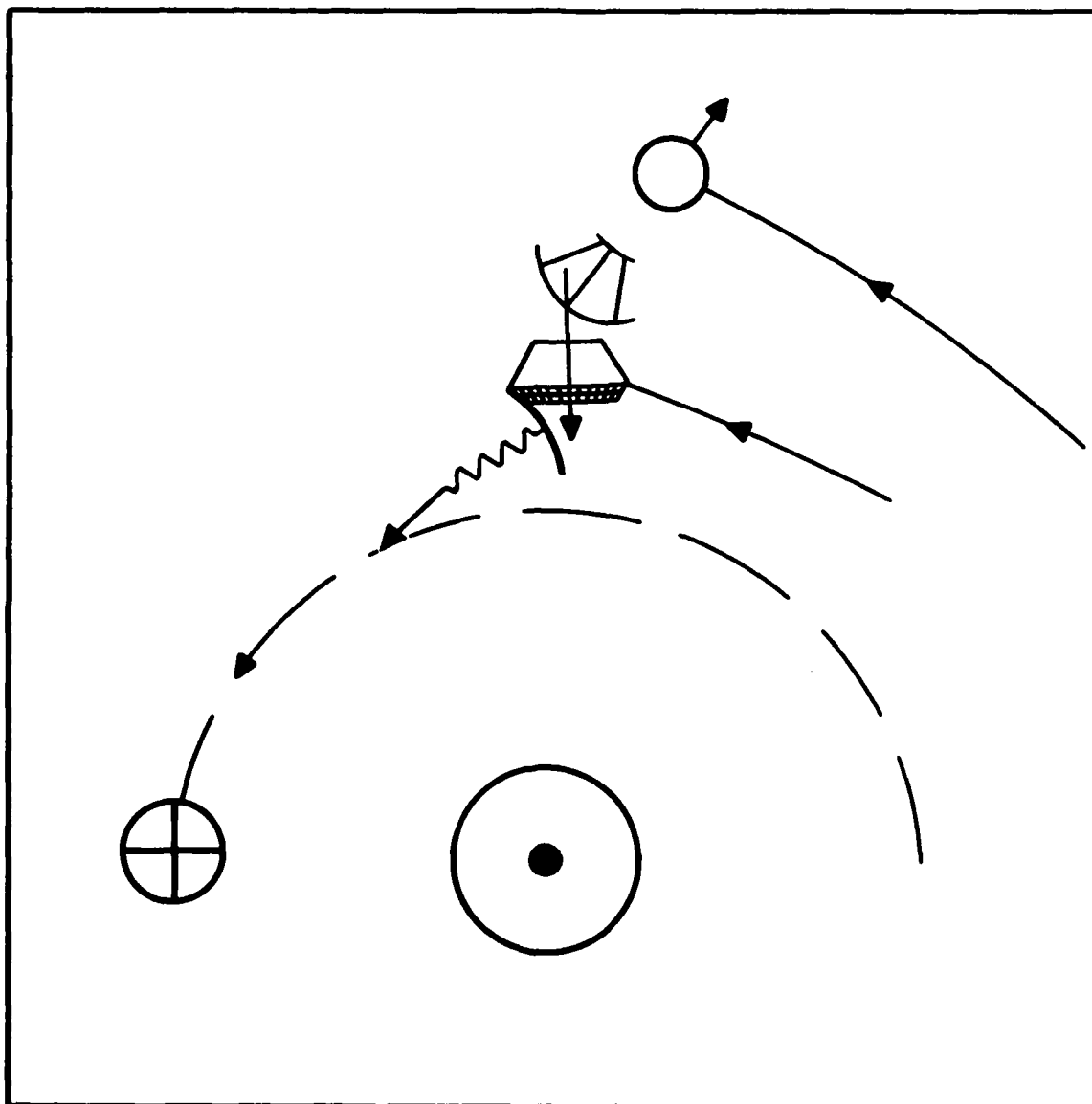


Fig. 3. Spacecraft Orientation at Time of Closest Approach to Mars

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2. Shaw, J. H., Burch, D. E., and Cummins, H. Z., Near Infrared Spectrum of Mars, Scientific Report 8. Ohio State University Research Foundation, Columbus, Ohio, November 1957.
3. Koval, I. K., "Results of Photographic Observations of Mars at the Kharkov Astronomical Observatory During 1954", Soviet Astronomy, 1 (3): 404-410, 1957.
4. Dollfus, A., "Étude polarimétrique de la lumière réfléchiée par la surface du sol de la planète Mars" Comptes Rendus, 227: 331-333, 1948, see also, "La polarisation de la lumière renvoyée par les différentes régions de la surface de la planète Mars et son interprétation", Comptes Rendus, 233: 467-469, 1951.

APPENDIX

General Construction of the Optical System

It is anticipated that the major role spectroscopy plays in astronomy will be paralleled in space science. A multipurpose spectrophotometer appears to be the most desirable design as it can be used for a variety of experiments with only minor changes. The optical system described herein utilizes mirrors and gratings rather than lenses and filters. Although the system is simple and unrefined as compared with its terrestrial antecedent, it is sophisticated as compared with most current space instrumentation. It should be re-emphasized that the instrument must survive the launch vibrations, which necessitates considerable development and testing time. Also, the instrument must be checked out prior to launch and must operate a few months later.

Basic Optics

Light from the planet is collected by the primary mirror A (Fig. A-1) and reflected on the Cassegrain mirror B, again reflected by the scanning mirror C to form an image of the planet on the plane D. The focal length of the system is therefore ABCD, and D is the focal plane. A pinhole H is located on D and will allow a certain portion of the image to go through to E, which is a light-chopper. As D is in the focal plane, the rays reaching all points below D will be divergent, and after being intermittently interrupted at E will reach a concave grating F. This grating does two things: it converges the rays onto the detector G, and disperses the light according to wavelength. Rocking the grating F through an

angle α and maintaining detector G in fixed position accomplishes a scanning in wavelength. By tilting the scanning mirror C in two planes, the total image of the planet can be made to sweep over the pinhole H and, thereby, expose all of the image to the analyzing detector. It is possible to make wavelength-scan rate very much higher than the planet-scan rate.

A detailed description of the instrument requires that it be categorized as follows:

1. Acquisition unit
2. Attitude control
3. Longitudinal and latitude scan
4. Wavelength scan
5. Data storage

Acquisition

Uncertainties in guidance make it impossible to predict in which quadrant (in a plane perpendicular to the payload axis) Mars will be at the time of the experiment; therefore, a coarse seeker is required to allow the instrument to acquire the planet and point the instrument within a few degrees of the proper direction. The acquisition unit should have the ability to find a planet situated within a half-sphere in front of the payload.

The coarse seeker is located in front of the Cassegrain mirror and has an unimpaired view forward. The seeker consists of a disc around which 4 photo-sensitive surfaces are located as shown in A, B, C, and D of Fig. A-2. A cylinder located in the center of this plane F supplies the system with a "sense"

of direction. Sensors A and C are connected differentially to amplifier G, which represents azimuth, and sensors B and D to amplifier H, which represents elevation. Azimuth and elevation are measured in relationship to the reference axis of the probe. The output of these amplifiers drives the corresponding servomotors which change the attitude of the instrument. The criterion for the system is a condition in which the four sensors receive equal light intensity. It is ambiguous that all sensors are looking into space. However, this can be avoided by modifying the criterion for the servo-system such that all sensors must receive an equal signal above a pre-assigned threshold.

Attitude Control

When the coarse sensor has acquired the planet and the system has come to equilibrium, the inputs to the two servo-systems are switched over, by a gating arrangement, to another set of sensors located on the periphery of the main mirror (Fig. A-3). A typical construction of these fine sensors is given in Fig. A-4.

The fine sensor consists of a plastic tube which is closed on one end and has a lens in the other. A mask is situated in the closed end, and inside the mask, a solid-state photocell. The focal length of the lens is so chosen as to put the planetary image on the photocell and the diameter of the hole in the mask is so adjusted as to be the same size as the planetary image at the maximum predicted miss distance. This adjustment is made because the greater the miss distance, the more severe are the requirements for angular control of the spectrophotometer. These four vernier sensors will be feeding into the same servo-system

as the coarse sensors, and should any of the vernier sensors lose the signal because of a sudden angular shift, the entire system will be switched back to the coarse-sensing process and will remain there until balance is re-acquired. Any angular shift in the system will make the image falling on B (Fig. A-4) change and, thereby, vary the amount of light incident on photocell C. The criterion for this set of sensors is that some signal must appear on all four vernier sensors in order to prevent the system from switching back to coarse sensing.

This particular sensing and acquisition system is based on a Mars mission with particular consideration given to the position of Mars relative to that of the Sun and Earth at the time of the experiment.¹ The angular speeds of the servo-system will be adjusted according to the maximum roll-rate and pitch-rate estimated for the payload. Because of the possible interference by the outside moon of Mars, Deimos, the possible angular speed of the servo-system employed should be kept as low as possible.

Longitude and Latitude Scanning

The terms vertical and horizontal scanning are used in reference to the vertical and horizontal axes of the payload. Because of the marginal communication expected between the payload and Earth at the time of the experiment, it

¹In the case of using this system for a Venus mission, some discriminating factor will have to be designed in order to cut out the interference from the Sun and give the system a method of distinguishing between the Sun and Venus. The type of coarse sensor employed will have to operate while the vernier sensors are in operation. As the light intensity from Venus is very much larger than that from Mars, the required sensitivity of the servo-system will not have to be changed, even though filters may have to be placed in front of the sensors.

becomes very important to arrange the scanning system in such a way as to lock the relationship between vertical and horizontal scan. If this is not done, it will be almost impossible to reconstruct a picture of distribution from the telemetered data. It is also necessary to be able to pinpoint the geographical area on the surface of the planet from which a given group of data is taken.

The scanning mechanism consists of a mirror-drum (A, Fig. A-5) with 12 mirrors. Each mirror in the wheel is slanted in consecutively increasing angles to the rotational axis so as to cause the image of the planet formed on the focal-plane (B, Fig. A-5) to sweep the pinhole (C, Fig. A-5). Thus, when the wheel rotates one turn, a vertical scan across the pinhole of the planetary disc is executed.

The angular difference between the start and end mirrors is determined by the minimum miss-distance contemplated for the mission; thus, at closest estimated approach, 12 vertical scans will be effected. Should the miss distance become twice this value, 6 vertical scans of the planet will be made.

As the mirror-wheel (A, Fig. A-5) is rotated, the image of the planet will sweep the pinhole C in the horizontal direction in such a way that one such scan is made for each mirror in the wheel. If the mirror wheel is allowed to rotate continuously, a point-scan in the vertical plane and a line-scan in the horizontal plane results, which would degrade the horizontal scan. Instead, the rotation of the mirror wheel is executed in discrete angular increments by a mechanism very similar to that employed in a stepping relay. The ratchet mechanism is divided into 144 separate steps, and each mirror in the wheel will be rotated in 12 separate steps in such a way as to arrive at 12 scans in the horizontal plane.

Wavelength Scan

As a wavelength scan will be made of each area of the planet and a certain time will be required for this scan, (e. g. , dwell time of the detector), no smearing of the signal will result from horizontal motion of the image. It is also necessary to synchronize the wavelength scan with the dimensional scan and to ensure the same wavelength-scan starting for each area of the disc. This is easily accomplished if the dimensional scan is an interrupted scan. As both vertical and horizontal scan are built into the wheel, a loss of one point in the vertical plane will automatically result in a loss of the corresponding point in the horizontal direction.

A light chopper D is located behind the focal plane (B, Fig. A-5). Placing this item where the divergency of the rays is small reduces the physical dimensions and the necessary displacement of the chopper. The chopper consists of a shutter operating as a self-resonant spring driven by a vibrator. The pulses which drive this mechanism also gate the signal amplifier for the detector in order that the signal-to-noise ratio may be increased.

Rays emanating from the pinhole C (of the chopper mechanism) fall on the concave grating F, in which focal point of the detector G is located. As the concave grating (which is suspended on an axis) is rocked through an angle α , radiation of different wavelengths strike the detector in order to accomplish wavelength scan. The focal length of the conical grating should be on the order of 30 cm in order to minimize aberration in the detector plane.

The manner in which the angle α varies with time is a close approximation of a sawtooth curve because the wavelength scan for each "point scan" must begin at the same wavelength. (This removes ambiguities in handling the data.)

The pulses drive two solenoids, one that effects the horizontal scan, and one that rocks the grating. This avoids the problem of reliability in operating electric motors or fast-rotating shafts in space environment.

Data Storage Media for Optical Experiment

The three basic data-handling problems associated with this experiment are acquisition, storage, and transmission. Limitations on bandwidth generally would preclude the playback of data in the real time domain; therefore, there will be a degradation of information in any type of analog data storage system. Consequently, a digital system is preferable to an analog system because data can be stored and transmitted in "on-off" representation.

Data can be acquired in the usual analog fashion but should be digitized immediately and stored, as well as transmitted, in digital form.

What appears to be an ideal solution to the digital storage problem is the use of magnetic cores, which are ideal in the sense that current requirements are nil except when actual read-in or read-out is performed. Information can be stored in 5 μ sec or less and can be read out as slowly as desired with no degradation of the signal. Magnetic cores can also store or read information either serially or in parallel which is necessary in the present experiment where a sub-scan of frequency and "greyness" is made for each spot of a criss-cross object raster. Necessarily, this information of frequency and "greyness" must

be acquired in parallel during the sub-scan and can be stored in parallel in a core-type memory with no difficulty. Read-out can then be done in serial fashion so as to satisfy bandwidth limitations.

Ferrite cores of 0.76-mm outside diameter are now available. An operational range of -150°C to $+100^{\circ}\text{C}$ is feasible, although the current required changes by a factor of two. The variation of current caused by temperature changes should be monitored by a thermistor, the characteristics of which closely follow those of the core. Cores can be manufactured which comply with reasonably rigid specifications. A block diagram of the data storage and handling of the instrument is shown in Fig. A-6.

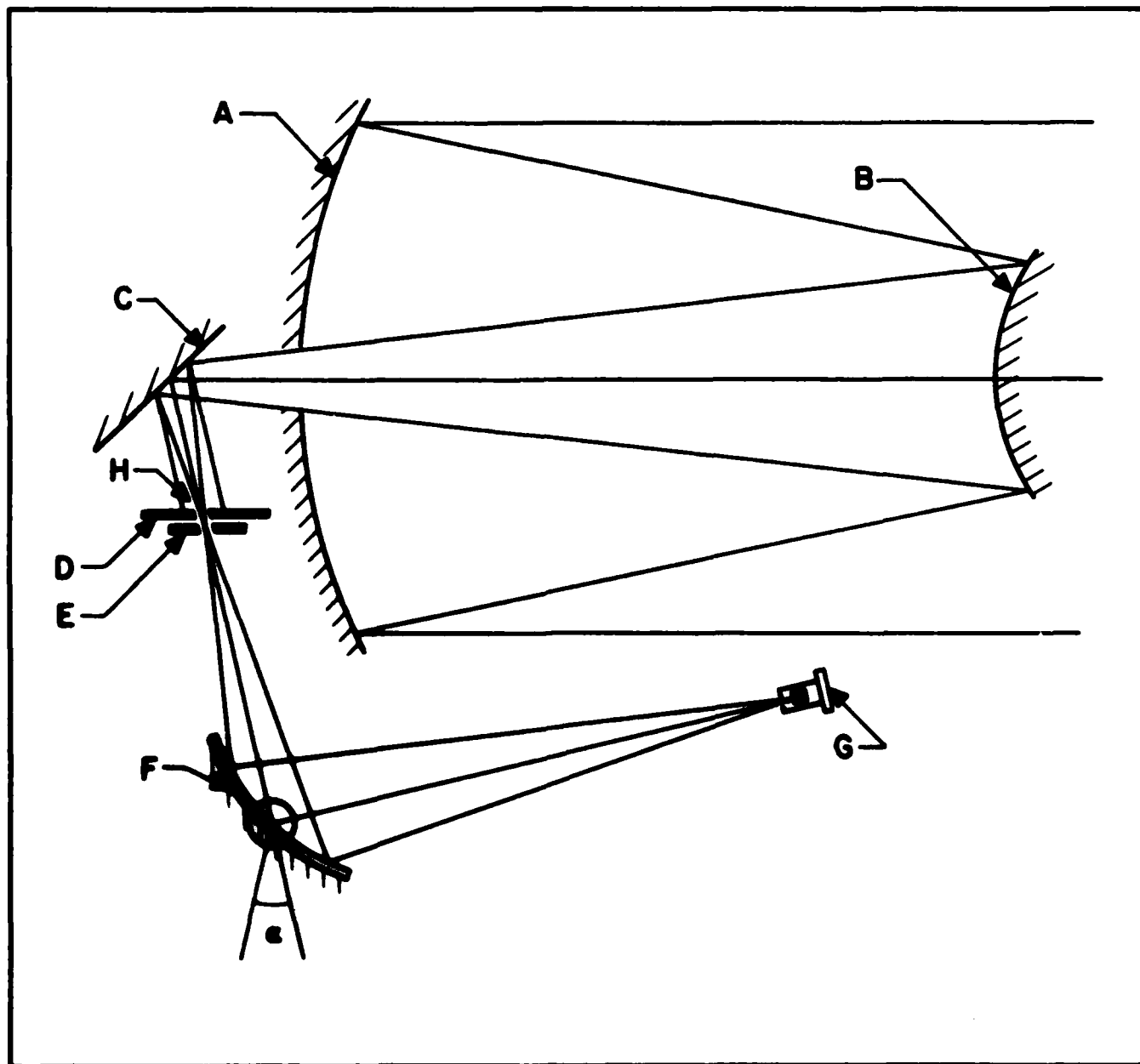


Fig. A-1. Basic Optical System

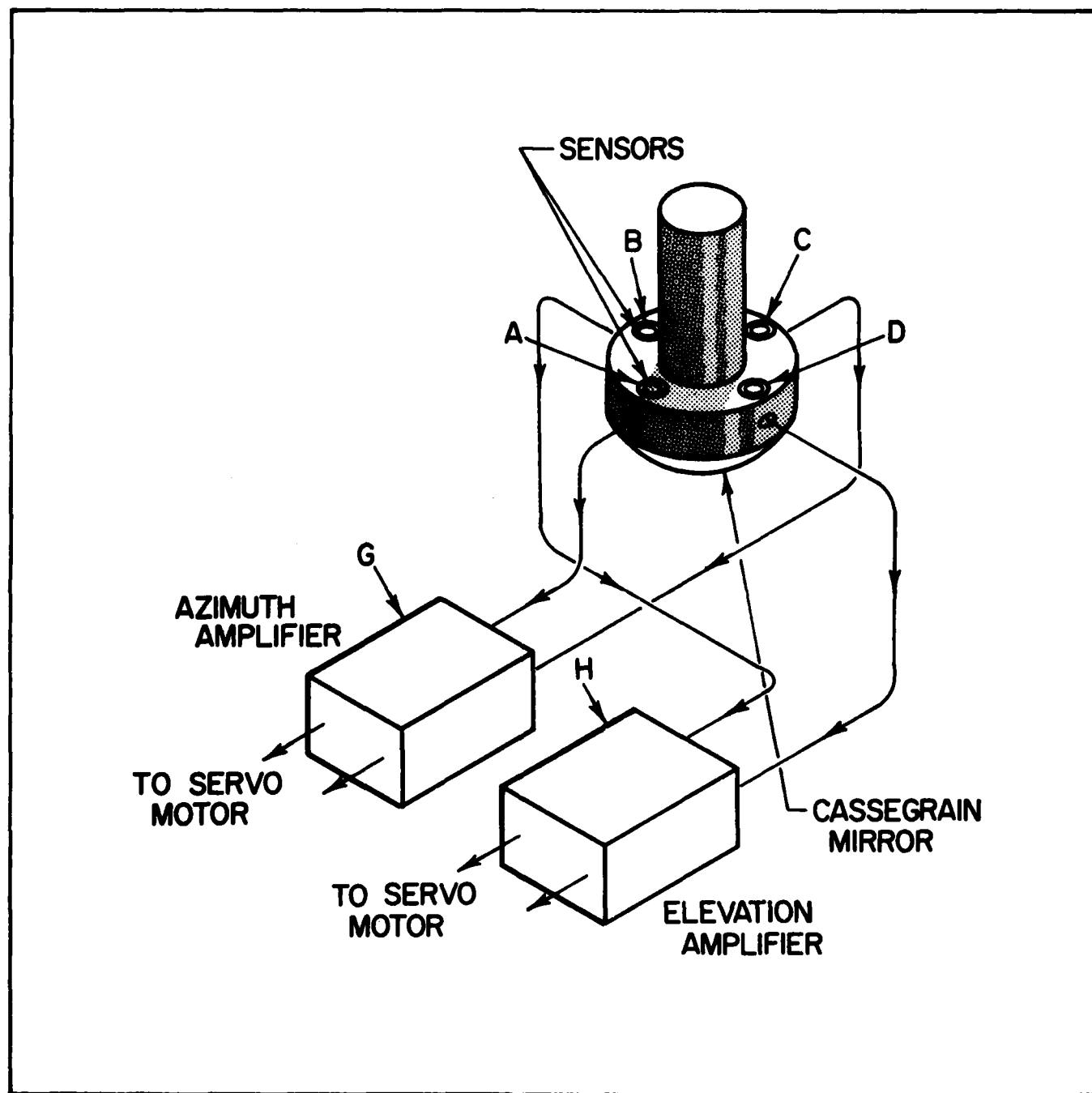


Fig. A-2. Coarse Sensor

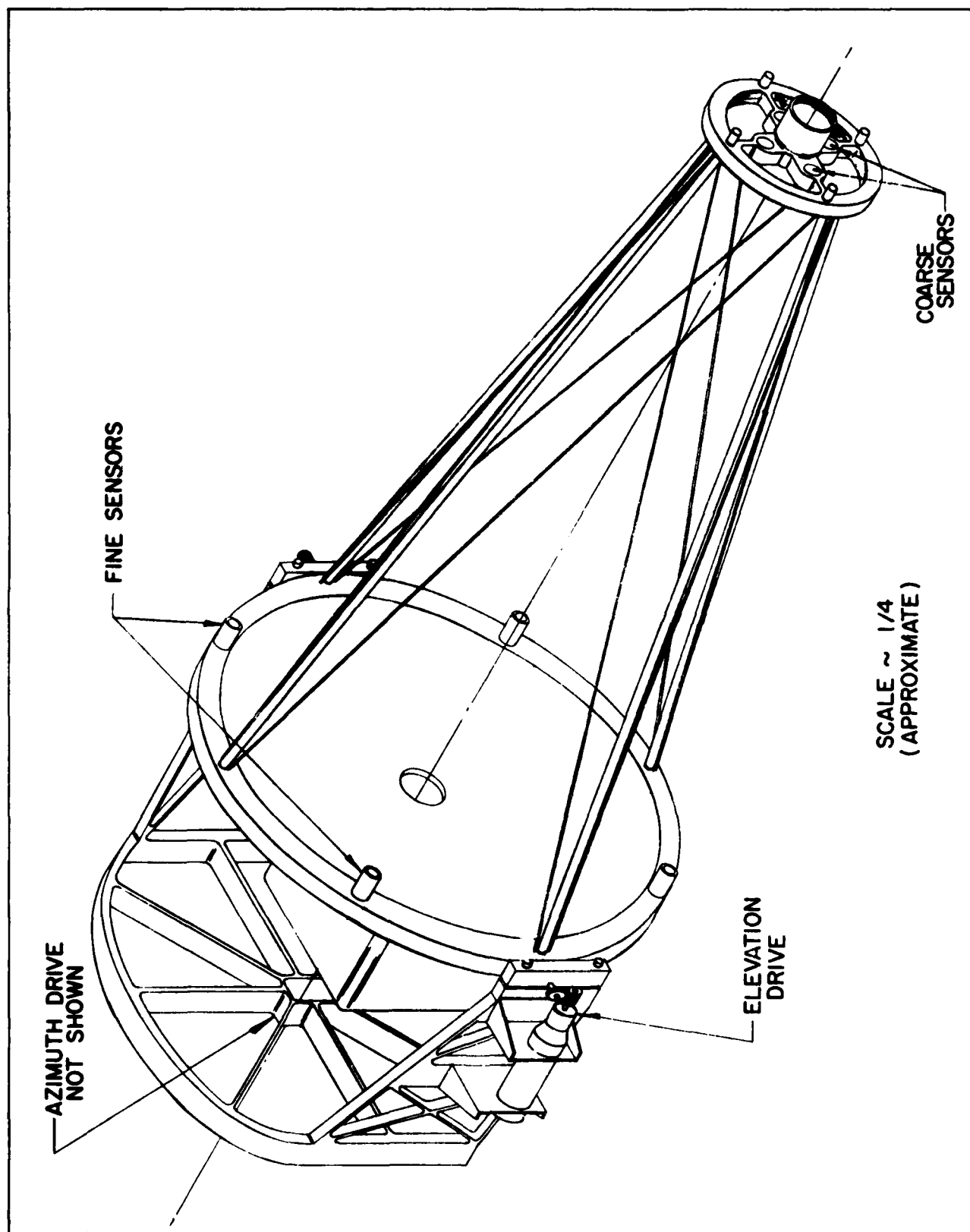


Fig. A-3. Interplanetary Station Telescope

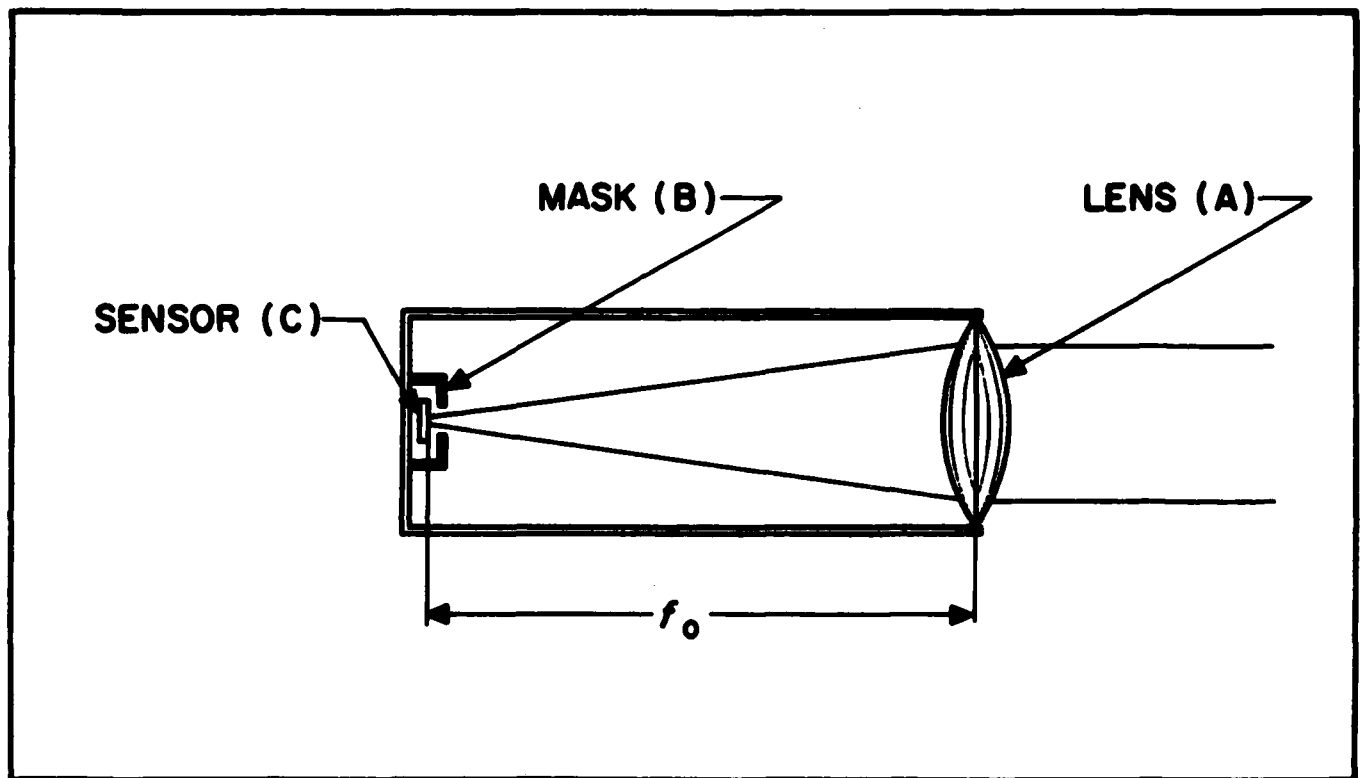


Fig. A-4. Fine Sensor

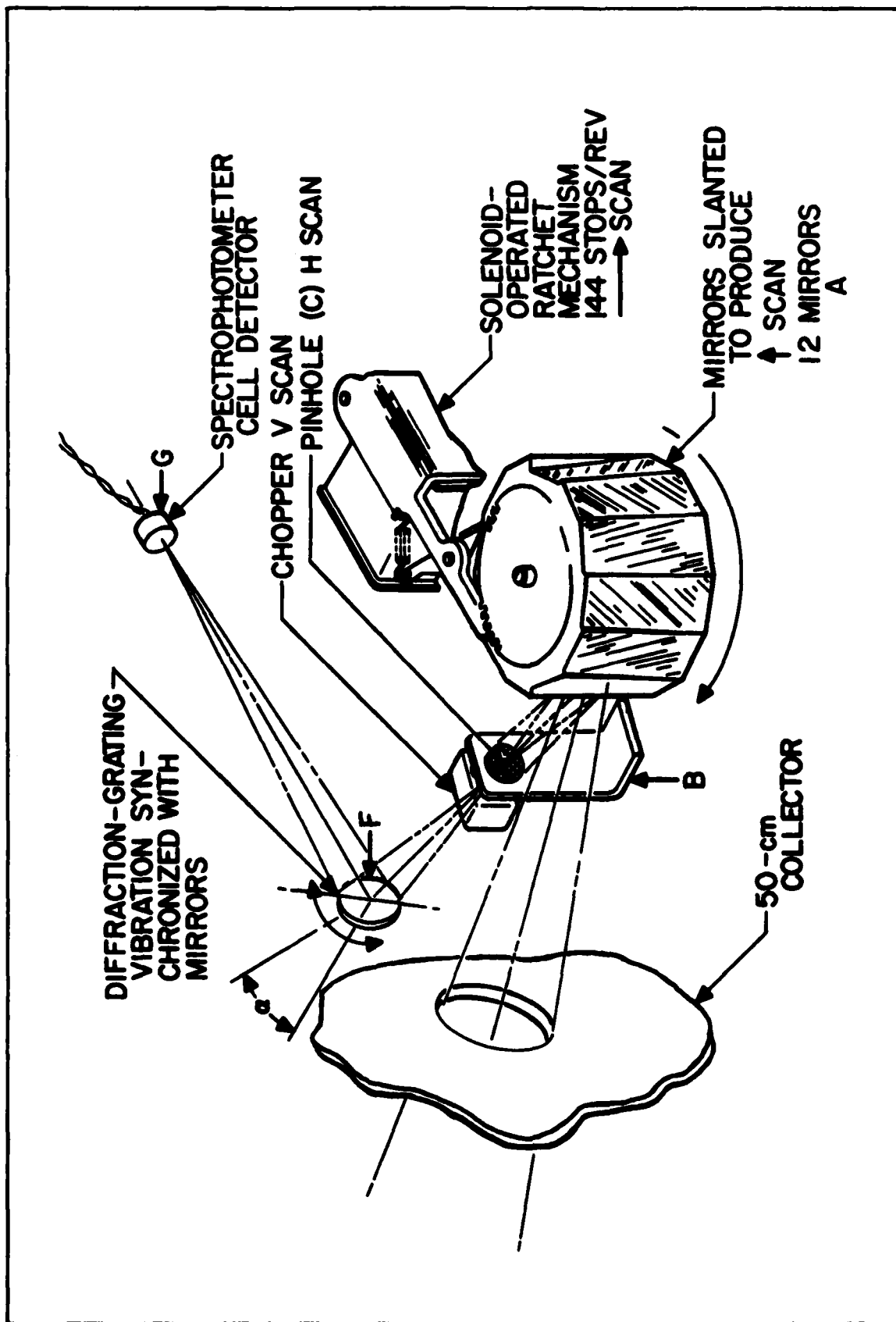


Fig. A-5. Image Scan Mechanism

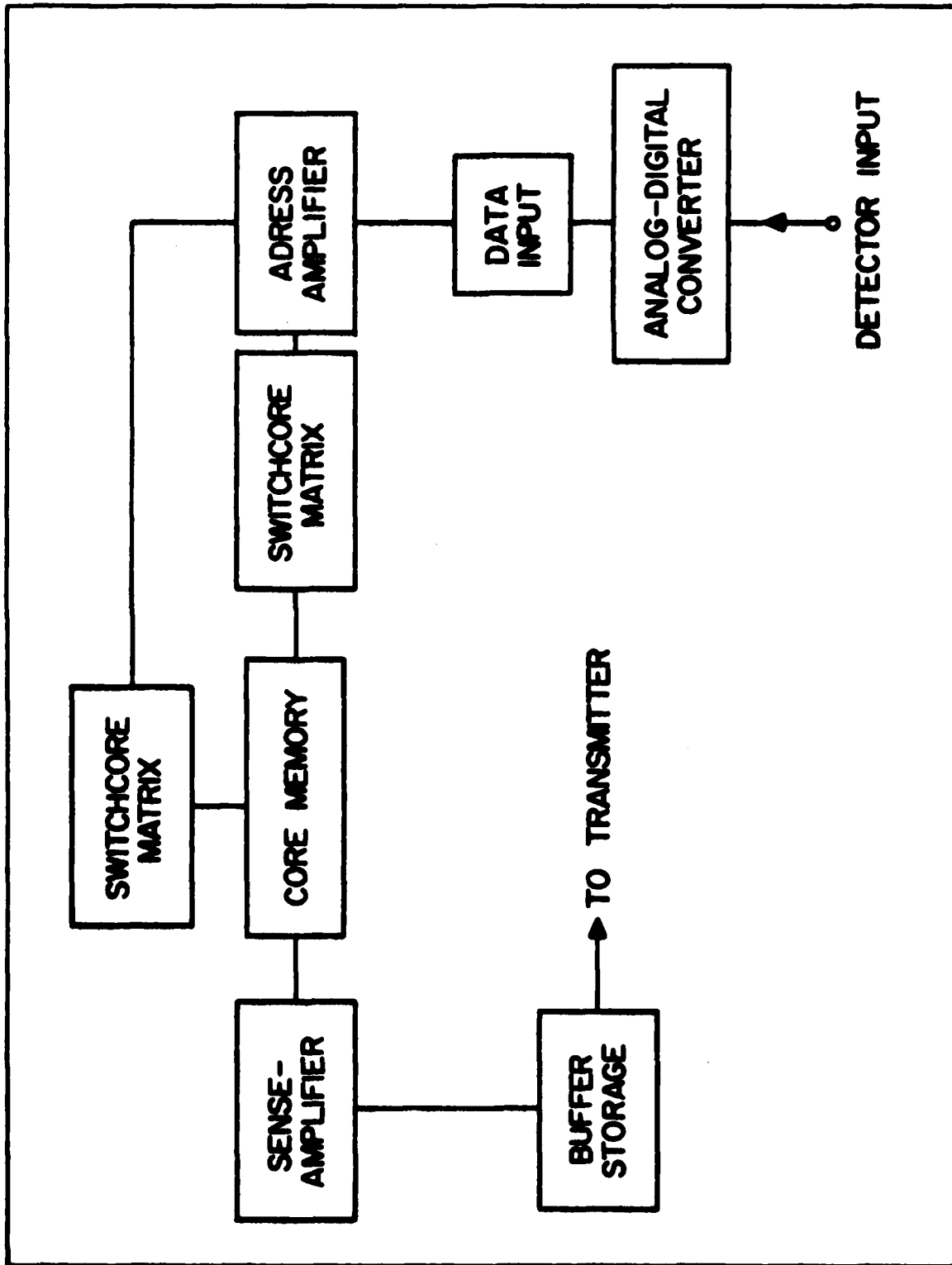


Fig. A-6. Data Storage and Playback

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